CHAPTER 7.—CONTROL OF DUST IN HARD-ROCK TUNNELS

By Fred N. Kissell, Ph.D.[1]

In This Chapter

- ✓ Finding the dust source
- ✓ Ventilation and dust collector malfunctions
- ✓ Upgrading the dust controls
- ✓ Design stage ventilation planning

This chapter explains how to reduce respirable dust[2] in hard-rock tunnels during excavation by using tunnel boring machines (TBMs). The first steps in combating a dust problem are to take dust samples to pinpoint the source, check the ventilation system, and check the dust collector. If the ventilation system and dust collector are operating properly, then other dust controls such as water sprays and conveyor belt scrapers must be upgraded. For tunnels in the design stage, recommended air quantities are provided.

FINDING THE DUST SOURCE AND LOOKING FOR VENTILATION MALFUNCTIONS

> **The first steps in fighting a dust problem are to take dust samples to pinpoint the source, check the ventilation system, and check the dust collector. Without knowing the exact source, efforts to reduce dust are hit-and-miss (mostly miss).**

Taking samples to pinpoint the dust source. In tunnels with high levels of airborne dust, the first task is to pinpoint where the dust enters the airstream. Most dust originates from rock breakage at the tunnel face, but the location where this dust enters the airstream can vary. Dust can leak from behind the TBM face shield, from gaps in the ventilation duct, or from a malfunctioning dust collector. It can be entrained into the air from the muck on a moving conveyor belt. It can even be shaken loose from the underside of the belt as it passes over the idlers. As a start, to locate the dust source, dust samples and air quantity measurements should be taken at the following locations:

[1]Research physical scientist, Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health, Pittsburgh, PA.
[2]An information source for controlling methane and diesel fumes in tunnels is Kissell [1996].

(1) At the portal or at the base of the entrance shaft
(2) At a location one-third of the way from the portal to the TBM
(3) At a location two-thirds of the way from the portal to the TBM
(4) At the rear of the TBM trailing gear, about 50 ft toward the portal
(5) At the middle of the TBM trailing gear
(6) At the front of the TBM trailing gear
(7) At the front of the TBM where ground support is installed
(8) At the outlet of any ventilation duct if the outlet is inside the tunnel

The dust samples can be 8-hr gravimetric filter samples, or they can be measurements taken with a light-scattering dust monitor. If the latter is used, repetitive readings must be made to ensure that observed changes in the dust level are not the result of changes in the TBM cutting rate.

Figure 7-1 gives the results from a dust concentration survey in a tunnel with an exhaust ventilation system. Both gravimetric filter and light-scattering measurements were made at regular intervals between the portal and the front of the TBM. The figure shows that, for this tunnel, most of the dust breathed by workers entered the airstream between the TBM and the portal, either from the conveyor belt or a leaking ventilation duct.

After the initial sampling, additional sampling in and around the TBM and trailing gear with a light-scattering dust monitor can provide useful information. Possible dust sources at the TBM include leakage from the head or from ventilation duct, emissions from rock drilling and

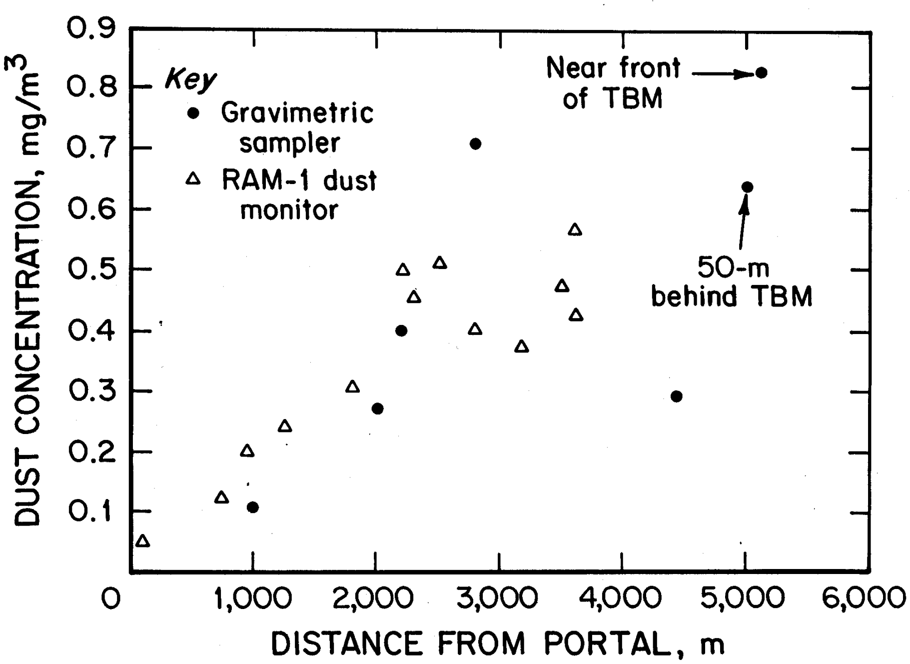

Figure 7-1.—Results from a dust concentration survey.

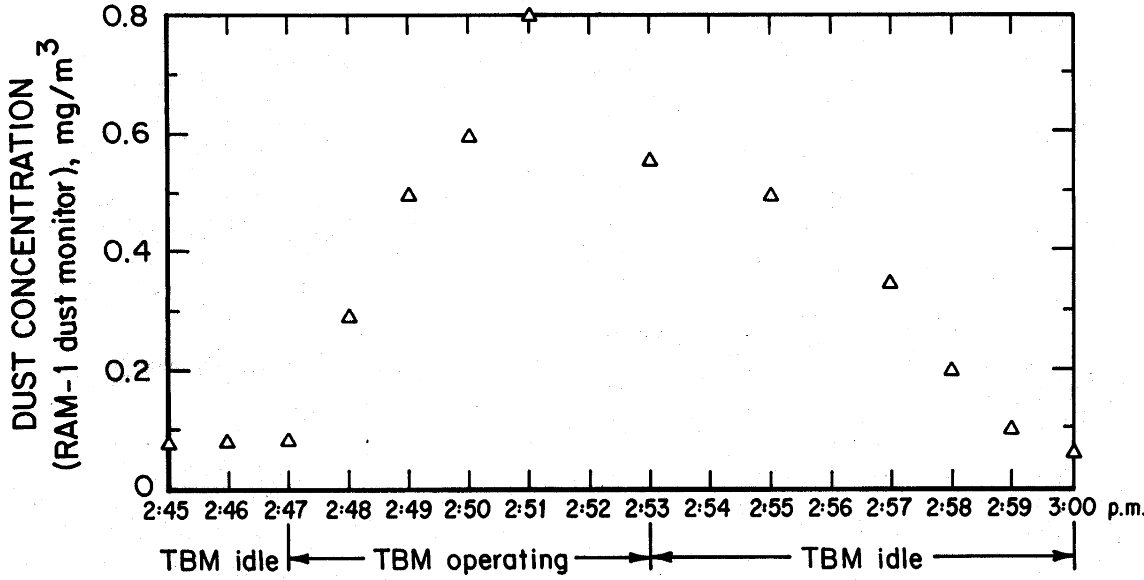

Figure 7-2.—Dust concentration measured near cutter head with TBM idle and operating.

conveyor transfer points, or the stirring of settled dust by work activities and cooling fans. To assess which of these are relevant, a light-scattering dust monitor can be used to measure the dust level close to each suspected source.

Figure 7-2 demonstrates the value of additional sampling around the TBM. In this tunnel, the only dust level of any consequence was measured at the front of the TBM near the cutter head as the cutter head operated. As the figure shows, the dust concentration rose (with little delay) after the cutter head began to rotate, then immediately dropped when the cutter head stopped. Rising and falling concentration profiles of this sort were only measured close to the cutter head, which indicates that the dust was leaking out somewhere close to the cutter head.

Checking the ventilation system. Air quantity measurements, taken at the same locations as the dust samples, are to ensure that the ventilation system is operating properly. Hidden leaks in ventilation ductwork are common and may cause abnormally low air velocities in a portion of the tunnel. Thus, high dust levels may result from the simple failure to deliver enough air. Ventilation systems with multiple fans will inevitably leak and recirculate some air. The recirculated air will usually contain dust, and the amount of recirculation may be enough to create a dust problem.

If recirculation is a concern, small holes should be drilled in the ventilation duct and the air pressure checked with the static pressure port of a Pitot tube. Exhaust systems should be under negative pressure, and blowing systems under positive pressure. Short regions of ductwork next to the fans may have the pressure reversed because of system imbalances, but reversed pressure regions should make up a very minor part of the ductwork.

If the dust concentration at the front of the TBM is much higher than that measured elsewhere, check to ensure that the ventilation duct is extended far enough forward. Exhaust duct must extend as far as the forwardmost worker, and ideally an additional 10 ft or more. Blowing duct must extend to within 20 ft of the forwardmost worker, assuming the jet of air emerging from the duct is unobstructed.

Unusually warm air from the TBM electrical equipment may indicate a malfunctioning ventilation system.

Occasionally, the ventilation system design includes some faults. Faulty designs inevitably result in higher dust levels. A common ventilation fault is the failure to provide overlap in auxiliary, or scavenger, systems. Figure 7-3 shows a properly operating scavenger system. The main fan acts to bring in clean air; the scavenger fan inlet is located in the clean air stream.

Figure 7-4 shows what happens when the proper overlap between the main duct inlet and the scavenger inlet is not maintained. The scavenger fan picks up some contaminated air returning from the face, so the amount of clean air delivered to the face is reduced.

Clean air delivery also suffers in mismatched scavenger systems. Figure 7-5 shows a blowing main ventilation duct mismatched to a blowing scavenger system. The scavenger fan intake is a mixture of clean air from the main duct and contaminated air returning from the face.

Another common problem found in tunnel ventilation systems is the low velocity zone created by moving similar quantities of air through ductwork in opposite directions. For example, figure 7-6 shows a tunnel with 5,000 cfm in a scavenger fan fresh air duct and 5,000 cfm in a dust

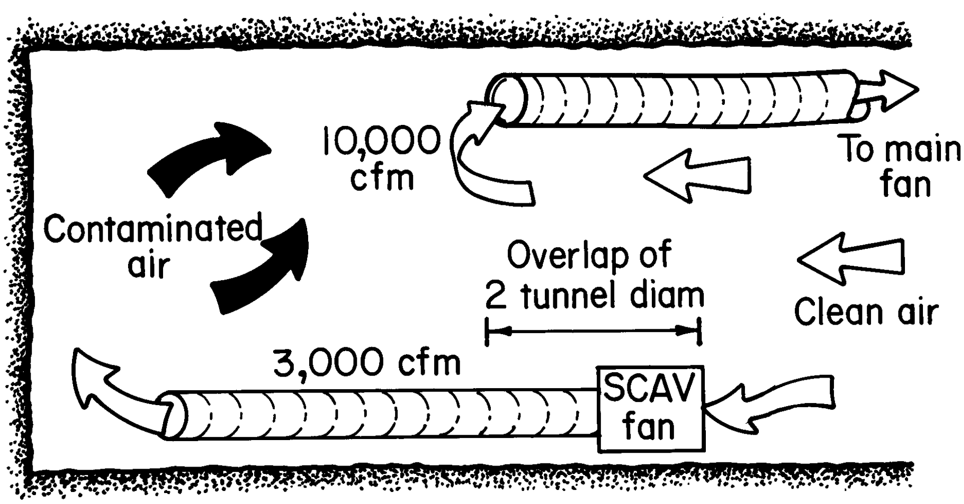

Figure 7-3.—Auxiliary, or scavenger, system with adequate overlap.

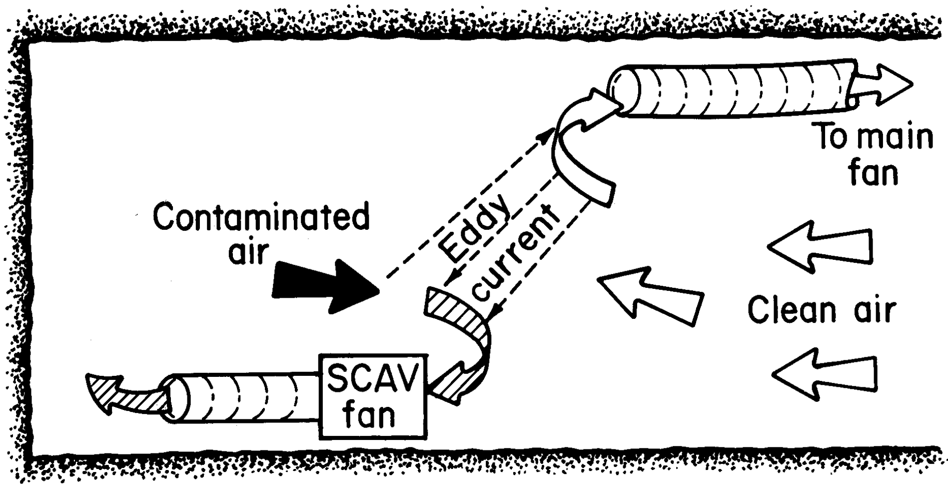

Figure 7-4.—Auxiliary, or scavenger, system with no overlap.

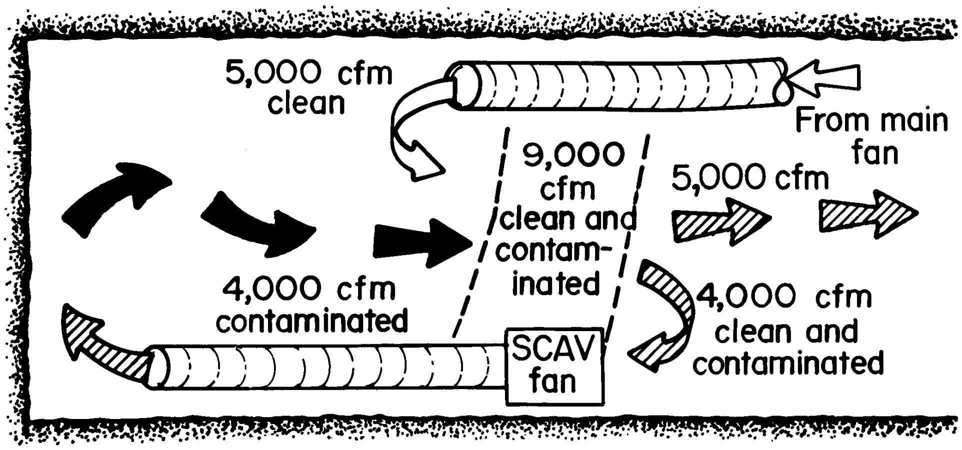

Figure 7-5.—Loss of ventilation efficiency from mismatched airflow directions.

collector duct. Because these two ducts have similar air quantities moving in opposite directions, there is a zone of low air movement between them. Therefore, dust sources in this zone can produce high dust concentrations.

It should be noted that if the scavenger fan duct shown in figure 7-6 moved air in the opposite direction, the air quantity delivered to the immediate face area would be increased from 5,000 to 10,000 cfm, and the amount of air moving through the zone between the ducts would be 10,000 cfm.

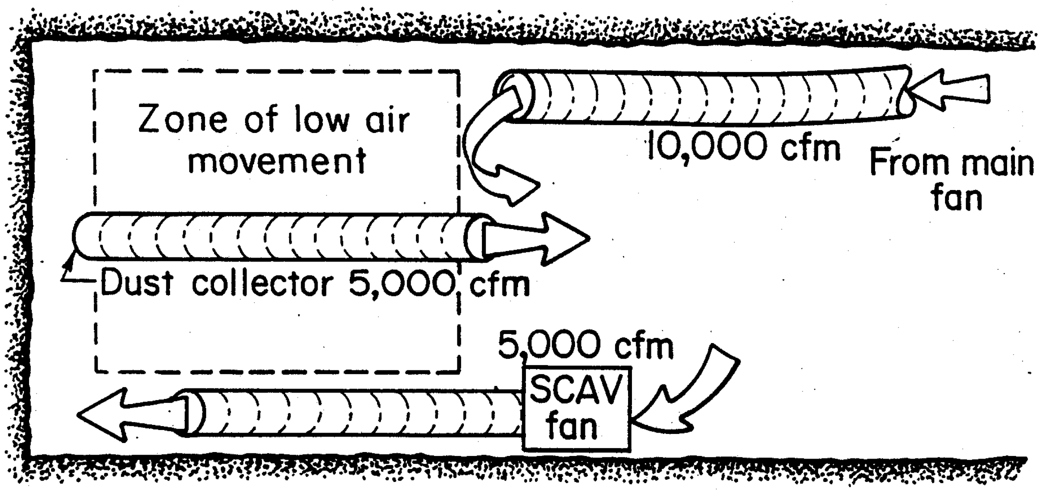

Figure 7-6.—Zone of low air movement is created because ducts have similar air quantities moving in opposite directions.

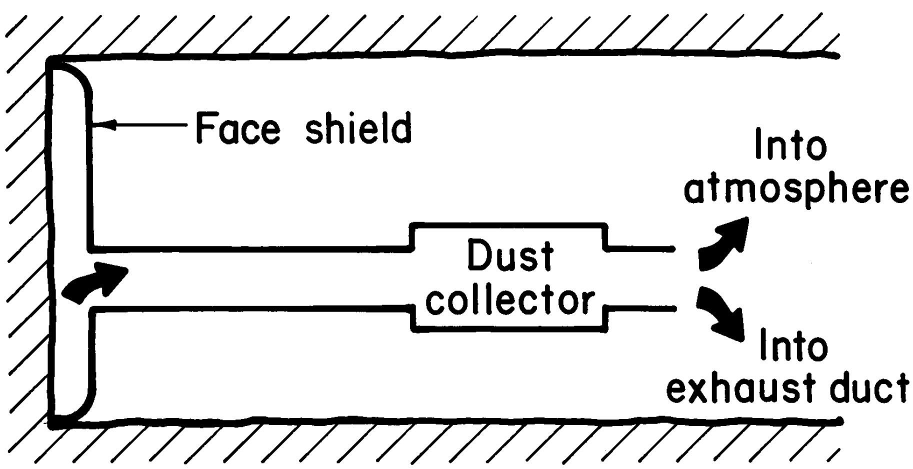

Figure 7-7.—TBM dust collection system.

Checking the dust collector. Most dust is removed via the dust collector system (figure 7-7), so it is important that the system works properly. Dust collectors in mines and tunnels can be high-maintenance equipment. Screens and filters often clog. Gaskets disappear, and access doors leak. Ductwork leading to the collector fills with coarse particulate that cuts off the air-flow. Fans located on the inlet side of the collector suffer rapid erosion of their blades. Filters can be improperly seated, with air leaking around them. Filters also develop holes from abrasion by larger sized particulate. A dust sample and an air quantity measurement taken in the collector outlet will reveal if the filters are working properly and whether the air quantity is adequate.

UPGRADING THE DUST CONTROLS

**Upgrade the other dust controls when checks of the ventilation and dust collector show no correctable problems. The water spray system should adequately wet the broken rock.
The dust controls on the drills and conveyor should also be upgraded if they are sources of dust. Consider using foam to control dust.**

Water sprays. Water sprays have two roles: (1) airborne capture and (2) surface wetting of the broken rock. Of the two, airborne capture is less effective. The typical water spray gives no more than 30% capture of respirable dust [Courtney and Cheng 1977]. Because of this, adequate surface wetting of the broken rock is most important. The vast majority of dust particles created during breakage are not released into the air, but stay attached to the surface of the rock [Cheng and Zukovich 1973]. Wetting the broken rock ensures that the dust particles stay attached.
A key factor is the uniformity with which the rock is wetted [Hamilton and Knight 1957]. For example, in coal mining, releasing water near the cutting picks of rotating shearer drums is far more effective at suppressing longwall dust than external sprays on the shearer body, because the rotating drums act to mix the coal and the water. Increasing the number of sprays can also promote uniformity of wetting. For example, Bazzanella et al. [1986] showed that dust suppression is improved by increasing the number of sprays on a shearer drum, even when the total water flow and nozzle pressure were held constant by using smaller orifice nozzles. Increasing the number of nozzles on the drum from 17 to 46 lowered respirable dust by 60%. This is better than the dust reduction afforded by most other techniques.

The lessons from this knowledge are twofold. First, it is best to fully wet the material during the breakage process. This is when most mechanical mixing is likely to take place, and it ensures that the benefits will carry over to any downstream secondary handling operation. Because of this improved mixing, it is better to have an additional 30 gpm at the cutter head than to have 10 gpm at each of three conveyor transfer points downstream. Also, it gives more time for the water to soak in and the excess to drain away. Second, best uniformity of wetting is achieved by using more nozzles at lower flow rates and ensuring that the nozzles are aimed at the broken material rather than just wetting an adjacent metal or rock surface.

As little as 1% of moisture on dry rock significantly reduces dust. However, since it is hard to achieve a uniform application of such a low moisture level underground, the best moisture content might be as high as 5%. Whether this much water is always practical is another matter, so one should ensure that the water is being uniformly applied before automatically raising the flow rate. For instance, on a TBM, sprays located on the rotating head will be more effective than fixed sprays at the crown, and sprays aimed to intercept the falling muck will be more effective than those aimed at the uncut face. One way to improve the airborne capture of water sprays is to raise the pressure to 500 psi or more. However, a marked disadvantage of high-pressure sprays is that they entrain large volumes of air. This can lead to more dispersal of dust than is captured. Because of this, their application is limited to enclosed or semienclosed spaces, such as the cutting head area of a TBM.

Aside from efforts to improve spray effectiveness, one of the most helpful actions a contractor can take is to provide some automatic feature that turns sprays on and off as needed. This allows sufficient wetting while helping to avoid the problems associated with overuse of water. If the dust standard is below 1 mg/m^3 because of silica, then spray water should be clean because the evaporation of dirty water can release dust from dissolved minerals. Frequent clogging of spray nozzles from particulates in the water line can also be a problem. In such cases, water line filtration can reduce clogging.

Control of drill dust. It is better to control drill dust at the source than to depend on ventilation to carry the dust cloud away. Drill dust controls can be particularly effective. The best method is to introduce water through a hollow drill stem [ILO 1965; Page 1982]. Less effective are water sprays at the collar of the hole and dry dust collectors that capture the dust cloud near the collar and filter it out [Page and Folk 1984]. Most failures of drill dust controls are readily found and corrected. Rather than mechanical breakdown of the controls, malfunctions generally result from oversights such as a failure to turn on water or to service clogged filters.

Control of conveyor dust. Conveyor belts can generate large amounts of dust. Methods to deal with belt dust are well known [Goldbeck and Marti 1996; Swinderman et al. 1997]. The following questions must be addressed if belt dust is high.

1. Are transfer points enclosed? A simple enclosure with a spray or two inside of it may be adequate. If this is not enough, the air inside must be exhausted to a dust collector or ventilation duct, with all of the leakage points on the enclosure sealed properly [Swinderman et al. 1997].

2. Is the material being conveyed adequately wet, but not so much that it leaves a sticky mud residue on the belt? When this residue dries, dust is released. Thus, an end result of excessive wetting can be an increase in belt dust.

3. Are the undersides of both the top and the bottom belts being wetted [Ford 1973] so that dust sticking to the belt is not shaken loose by the idlers? Does the belt stay wet or is it drying out and releasing dust?

4. Are the belt scrapers working properly? Is a second set of scrapers being used? Has a belt washing system been installed [Bennett and Roberts 1988; Stahura 1987]?

5. Is the belt running true and not spilling its contents [Swinderman et al. 1997]?

More information on conveyor belt dust control can be found in chapter 6 on hard-rock mines.

Foam. The use of foams for dust control has been studied extensively in coal mines. Here, foam works better than water, providing dust reductions in the 20%-60% range compared to water. Foam also can produce similar results at lower water use. Seibel [1976] compared 15-20 gpm of high-expansion foam to 19 gpm of water at a belt transfer point. Compared to water, the foam averaged 30% more dust reduction. Mukherjee and Singh [1984] found that foam released from a longwall shearer drum cut the dust 50% compared to conventional sprays on the drum. Also, the system used only half the water. The drawback of foam is high cost.

The benefits of improved mixing and uniformity of wetting have also been obtained with foam. Foam effectiveness was far greater when it was mechanically mixed in with the coal [Mukherjee and Singh 1984] or silica sand [Volkwein et al. 1983]. Page and Volkwein [1986] have published a comprehensive review of foam for dust control in mining and minerals processing.

DESIGN STAGE VENTILATION PLANNING

- **The quantity of air needed for dust control**
- **Whether to use exhaust or blowing ventilation**

When tunnel excavation is underway, major ventilation upgrades are usually not practical. However, for tunnels in the design stage, sufficient airflow must be planned into the design. Ideally, ventilation systems should be designed to achieve 100 ft/min air velocity throughout the tunnel, including the TBM and its trailing gear. This 100 ft/min must be regarded as a minimum if the rock has over 10% of crystalline silica. For large-diameter tunnels, 60 ft/min is the minimum. Other considerations, such as dilution of methane gas or diesel fumes, may require higher velocities.

Whether to use exhaust or blowing ventilation is always a key issue. Within the region of the TBM and trailing gear, exhaust ventilation is best for dust control. When exhaust ventilation is used, the zone of low air movement between the ventilation and dust collector ducts (see figure 7-6) is avoided, and both systems work together to maximize fresh air delivery. Between the rear of the trailing gear and the portal, the main ventilation system could be either exhaust or blowing. If the main ventilation system is exhaust, then the ventilation and dust collector ducts from the trailing gear must feed directly into it. If the main system is blowing, then some overlap with the TBM trailing gear systems must be maintained, as shown in figure 7-3.

Ventilation estimates must consider a realistic estimate of air leakage in the ductwork. In planning a tunnel ventilation system, a duct leakage of 20%-50% can be expected. The most common mistake in ventilation system design is the failure to consider enough leakage. Contractors should avoid using flexible, spiral-wound ventilation duct for any purpose other than as a short connection between sections of rigid metal duct. The pressure drop in spiral-wound duct is very high compared to smooth metal duct.

Finally, designers of ventilation systems must also plan to extract a sufficient quantity of air from the cutter head area behind the dust shield in order to prevent dusty air from leaking out. Myran [1985] has given the following recommendations on the amount of air that should be extracted:

Tunnel diameter, ft	Airflow range, cfm
10	4,000-6,000
15	7,000-10,000
20	12,000-17,000
25	19,000-26,000

These airflows can be hard to achieve because they require large fans and ductwork, not to mention large dust collectors. Why such high airflow from what is presumably an enclosed space? First, the stirring action of the large rotating cutter head creates considerable source turbulence, which disrupts the normal inflow of air that acts to contain the dust. Second, there is far less enclosure of the cutter head than a casual inspection of a TBM would indicate. Depending on the TBM design, the entire belt conveyor access space can be wide open. Also, there is open space when the grippers at the head expand to press out against the tunnel walls. In addition to raising the airflow, dust reduction efforts have focused on reducing the open space available for the dust to leak out by enclosing the conveyor tunnel and by installing single or even double sets of rubber dust seals between the grippers and TBM body.

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